DETECTION, MAPPING, AND CHARACTERIZATION OF GROUNDWATER DISCHARGES TO BISCAYNE BAY SOUTH FLORIDA WATER MANAGEMENT DISTRICT, CONTRACT C-15870

Final Report
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John R. Proni, Hector L. Casanova, Charles M. Featherstone
Ocean Chemistry Division
Atlantic Oceanographic and Meteorological Laboratories
4301 Rickenbacker Causeway
Miami, FL 33149

Harold R. Wanless and Christina Gonzalez
Department of Geological Sciences
University of Miami
Coral Gables, FL 33124

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I. Introduction

The work effort entitled "DETECTION, MAPPING, AND CHARACTERIZATION OF GROUNDWATER DISCHARGES TO BISCAYNE BAYSFWMD CONTRACT C-15870", was undertaken to improve existing knowledge on groundwater springs discharging into the Biscayne Bay. The general objectives of this study are to identify the locations of historical springs in Biscayne Bay and to detect and characterize freshwater flows from present-day springs that discharge to the Bay. The present study also identifies additional information and studies that are needed to fully understand the role(s) of present day springs and how such springs might be affected by current and future water management practices. Sediment studies work efforts are led by Dr. Hal Wanless at the Geology Department of the University of Miami.

Using various techniques, including helicopter observations, field observations and measurements, water property measurements and sediment analysis the following types of information were obtain: (a) location of points of discharge of some historical springs and springs that are occasionally active, (b) preliminary indications of source locations of springs waters, (c) quantities of flow discharges at currently active springs, (d) spatial distribution of parameter valves about a spring, (e) timing of flow discharges, (f) water quality analysis of the spring flow.

Several difficulties were encountered in the field program, which affected the amount of information developed as of the date of this final report (December 6, 2004). Nevertheless, significant information was obtained and is reported herein and in previous quarterly reports. Analysis of data obtained will be continued beyond the date of this final report and will likely appear in the form of one additional report.

II. Summary of Activities

A historical survey of springs was carried out and the results of that survey reported in the first quarterly report in this project. A helicopter survey was carried out on the October 7, 2003 during which sixteen water surface slicks, potentially identifying groundwater springs were observed. The slicks were then located by GPS coordinate and listed in Table 1 of the First Quarterly Report .The First Quarterly Report was provided to the South Florida Water Management District (SFWMD) on February 6, 2004.

In February and March of 2004 sampling, using a canoe, was severely limited by wind condition. To improve the ability to sample, AOML sought to obtain a small boat (a twenty one foot Parker). Decisions were reached regarding appropriate sensors for measurement of conductivity (salinity) and temperatures at a number of fields sites and order such units with the appropriate sensors. The manufacturer gave a mid April 2004 delivery date. Two historical sites were visited and sediment cores were obtained. No active flow was observed. The location of a spring called the "Ricisak" spring was determined. The Second Quarterly Report was provided to SFWMD on April 6, 2004.

In May, June and July many small springs were observed and their GPS coordinates tabulated. AOML had not yet received the boat it had requested, so samples continued to be gathered on the canoe. The daily cycles of thunderstorms during the afternoons caused the limited data gathering during this time. Various logistical, equipment, and personnel difficulties resulted in twelve successful days of sampling through June. Despite the risk of thievery or loss, AOML decided to purchase and install in-site sensors, which could provide continuous data records of salinity, temperature, depth of sensor (water height above sensor), pH, chlorophyll and flow velocity. AOML decided to utilize a transverse Doppler flow measurement system because of personnel reports that significant flow speeds were seen at least at two of the springs. The original intent was to use seepage meters, although some questions arose in their use. Seepage meters may well be used in subsequent studies. The sensors ordered for multiple site measurements of salinity and temperature were found to be defective and were returned to the manufacturer in Iceland for repair. Data results obtained are presented in the third quarterly report to the SFWMD dated September 3, 2004.

During August, September, October and November various types of data were obtained, although logistical and instrumentation difficulties continue to affect the total amount of data obtained. The data results obtained are presented in the Final Quarterly Report, which is attached as an appendix to this report. As of the date of this report (December 6, 2004) AOML has received the 21-foot Parker boat for sampling, but is carrying out repair work to make it operational. AOML has now working CTD mini probes from Iceland, a working YSI unit (without a Doppler) and is awaiting delivery of the repaired YSI unit with the transverse Doppler system. Sediment samples are being analyzed by Dr. Harold Wanless and Christina Gonzalez at the University of Miami.

III. Field Observations

Currently Active Springs

Harold Wanless and Graduate student Christina Gonzalez spent over 40 days in the field by canoe searching for and documenting artesian springs in the inshore portions of central Biscayne Bay. In addition, they spent about 6 day with NOAA or Biscayne National Park personnel searching more offshore waters and areas to the north and as far south as Turkey Point. Success in discovering and locating springs in the inshore waters of Biscayne Bay depends on very calm water and times when the south Florida Water Management discharge canals are not open. When the water is glassy the schleren (blurry water mixing zone can be seen where fresher artesian spring water is mixing with the ambient Bay water. These schleren can then be followed to the spring source. In shallow water, spring discharge can also be seen as a disturbance on the water surface.

Springs can be divided into two types: larger persistent springs and smaller ephemeral springs. The larger persistent springs are 1-4 meters across and have flow throughout the year, even through the dry season. These persistent springs form depressions in the bottom surface because the soft sediment sequence overlying the rock has been washed out exposing the limestone surface and the rock conduit maze through which the springs discharge. In the dry season these springs have discernable flow only near low tide; in the wet season they flow throughout most of the tidal cycle. Discharge can be strong even during the dry season. In the wet season, when the nearby floodgates are opened, the flow of the persistent springs greatly diminishes. About six of the discovered springs are persistent.

Ephemeral springs are less than 50 centimeters across and have visible flow only during the wet season during times when the canal floodgates are closed, which increases the freshwater head from the adjacent mainland. Most of these springs emanate through small openings in the soft sediment. These sites are invisible when the springs are not flowing. During the strongest wet season flow, the area offshore Deering Estate and south for about a mile had many areas where there were 1 to 4 small springs flowing per square meter.

This study focuses on areas where the natural bottom (limestone and overlying sediment) has not been disturbed. There is also abundant freshwater spring discharge through the limestone walls and bottoms of the numerous channels cut into the near shore bottom (in association with the SFWMD flood-control canals and channels dredged for boat access. In addition freshwater springs occur within the dredged boat harbors (such as at Deering Estate), dredges ponds (as at Montgomery Botanical Center) and in natural channels the adjacent mangroves (as at the Deering Estate).

In late November 2004, we have been told about several springs offshore within central Biscayne Bay, and we are presently attempting to arrange a diving visit to one of these sites.

Historical Springs

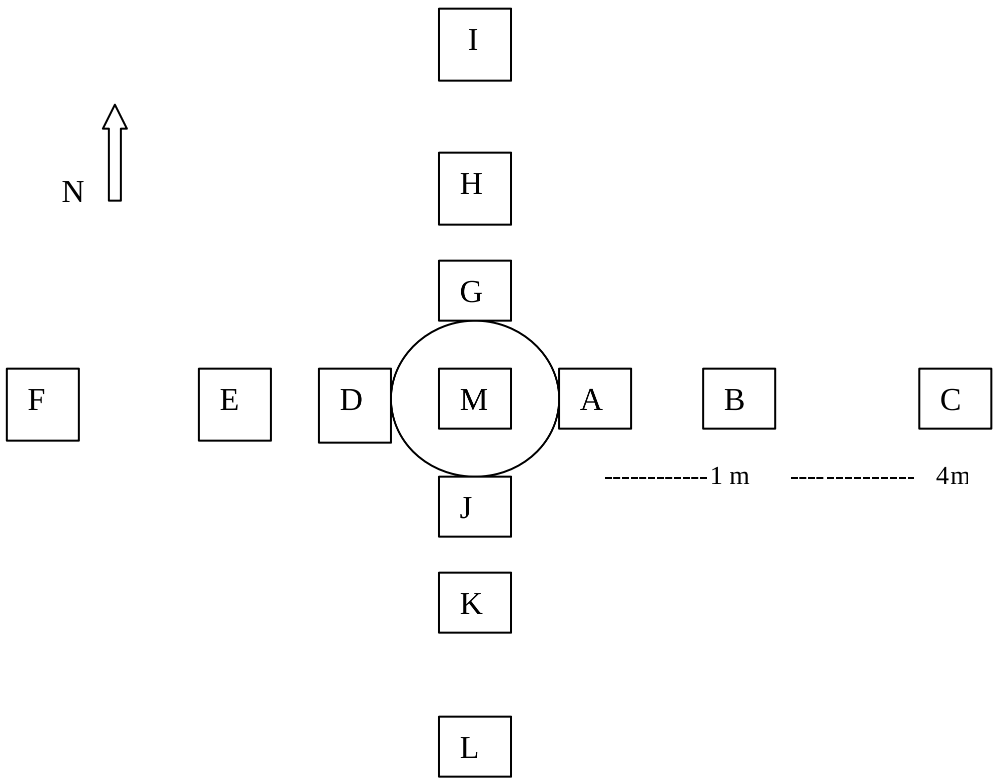
Several historically active springs are well documented in aerial photographs. These were relocated and examined in the field. There was no visual evidence for their presence or observed flow. One had a barren soft-sediment bottom within seagrass meadows in the vicinity of the historical springs. The sediment sequence beneath the bare bottom area was much softer (determined by probing) that in the adjacent areas, and we took cores to assess whether there was a faunal anomaly.

In interviews with people in their seventies and eighties who grew up along Biscayne Bay, we have heard descriptions of many near-shore springs that were active from the Brickell area (north of Rickenbacker Causeway) south past Coconut Grove. None of these are reported as active today, but they should be checked out during wet-season high-water periods.

One reported historical spring was at the south end of Key Biscayne, just west of the Lighthouse in Bill Baggs Cape Florida State Park. On visiting this site and discussing it with the State Park officials, it seems more likely that this was a freshwater pond within the Key and not an artesian spring.

Sampling

We collected sediment surface samples in radiating north-south and east-west transects from two active persistent springs in an effort to see whether there was an easily distinguishable sediment signature of the sites of freshwater discharge. The sampling patterns is as shown below.



Surface grab sediment samples were wet-sieved into grain sizes: > 4000 µm, 4000-2000 µm, 2000-1000 µm, 1000-500 µm, 500-250 µm, 250-125 µm, 125-63 µm, and < 63 µm; and dried. Each grain size for each sample of each spring was then analyzed for relative composition. Graphs were produced for each sample: one graph for foraminifer composition, and one for all other sediment components.

The sediment samples were viewed under a **complex light microscope,** and foraminiferal species were determined with the aid of previous foraminifera studies (see reference list). There was some trouble in species identification as most reference photos are SEM photos. Many species, or subspecies appear to be very similar and distinguishing the two or three species from one another would involve more intensive procedures, such as SEM, looking at the inner chamber arrangement, and a closer look at the tooth aperture. Therefore, in the data provided, I have sometimes grouped two or more species together, and have also identified the foraminifera to the best of our ability at this time. Abundances were visually estimated as <15%, 15-50, and 50-100% of foraminiferal population.

IV. Discussion of Data Obtained

In-situ Instrumentation

Recording of in-situ salinity (conductivity), temperature, water depth (height of water above the pressure sensor), velocity, turbidity, and chlorophyll data time series began in October 2004. The in situ measurements were made at spring number BBS21 (Ricisak). Figures 6 and 7 in the appendix are photos of the spring showing the groundwater plume. Figures five also shows the YSI ADV 6600 instrument set up at the spring site. Spring BBS21 consists of multiple bottom holes, separated by rock, all in an opening about 2 meters by 3 meters in extent. On October 14, 2004, the YSI ADV 6600 was lowered into one of the bottom holes in the spring. The instrument purchased brand new from the manufacturer, flooded immediately and did not yield any reliable data. The (flawed) data from the instrument suggested a higher than expected spring vertical speed at a certain time in the total cycle during which high salinity values were recorded. The flawed YSI ADV 6600 was sent back to the manufacturer for repair and as of the date of this report, has not been received.

A second YSI unit, not having a current measurement capability was tested on October 28, 2004. The data for 10/28/2004 is shown in figure 2 of the appendix. On November 2, 2004, the YSI was deployed and was retrieved on November 4, 2004 (see figure 3 of the appendix) Shown in the graph of figure 3 are temperature, salinity, and depth (water height above the YSI pressure sensor). A clear tidal signal is seen with the water depth ranging from 1.08 meters to 1.56 meters. A salinity signal is also observed which correlates with the tidal signal. Highest salinity values, e.g. 23 ppt, are seen to correspond high tide instances and the lowest salinity values, e.g. 10 ppt, are seen to correspond to the low tide instances. The daily heating cycle of water in Biscayne Bay is seen in the temperature signal where temperature range from a high of approximately 28.5 °C to a low of 26° C. Turbidity data seen in the lower panels of figure 3. Data in the period 11/05/2004 to 11/10/2004 are shown in the appendix.

Chemical Sampling Data

A result of chemical sampling and analysis for springs BBS21, BBS22 and BBS26 are presented in the third quarterly report and in the appendix of this report. Silica was analyzed in the samples to support the view that samples were gathered in groundwater spring flows. The high silica values observed support the groundwater flow identification of samples. The samples are seen to contain ammonium and phosphate. Samples were gathered in July and in August 2004.

Sediment Data

Sediment data is tabulated and presented in graphical form in the Appendix, Separate graphs are provided for a) benthic foraminiferal composition and b) all other sediment components. Graph spreadsheets are according to concentric rings about a spring. Samples were taken in 4-way transects, from edge of spring to 1 m away to 4 m away, first heading east then west, then north, then south, then one sample from the middle (center) of spring. See sampling diagram above.

Although some trends in the forams may be seen (some species of forams are correlated with one or two grain size categories, and other species with different grain sizes, and these forams will show consistently in each sample of both springs when those grain sizes are present), the relative abundance of species indicative of stressed environments, or lower salinity waters, is not observed to match the same sampling locations of each spring, which would indicate an effect of the spring on foram assemblages of the area. The most common (usually occurring as greater than 15% of the sample) forams present in almost all the samples were Ammonia beccarii, Ammonia beccarii v. parkinsoniana, Triloculina rotunda (more frequent in BBS22 than in BBS21), Triloculina oblonga (more present in BBS21 than BBS22) and Triloculina trigonula. It is important to note that those species, which I grouped in T. trigonula most closely, resemble T. trigonula. I was unable to cross-reference these forams with outside references, and without the aid of SEM, I needed to group them as "most likely resembles." All the forams in this species group look like each other, however.

There were some positive correlations (in both springs) with species content and distance from the center of the spring. The following is based on 15-50 % of sediment sample. Therefore, though some of the following species were not abundant to 50%, they may be present is lesser quantities.

1. *A. beccarii* is frequent in all but a few samples, regardless of sample location.
2. *T. trigonula* appears more frequently in BBS21 over BBS22 (BBS21 has 3 tests in ADGJ, 4 in BEHK, 2 in CFIL, and 1 in M (for 15-50%); whereas BBS22 has 2 in ADGJ, 2 in BEHK, 1 in CFIL, and none in M.
3. *T. oblonga* is present in the 15-50% range in about half the samples from BBS21, in any location, but is absent from all samples in the 15-50% range in BBS22 except C.
4. *A. beccarii v. parkinsoniana* appears in A and J samples of both BBS21 and BBS22, and is absent (in 15-50% range) from all other samples, with the exception of BBS21-F.
5. *Articulina mucronata* (associated with larger grain sizes), is absent (in 15-50% range) in ADGJ from both springs.
6. *Triloculina rotunda* appears to increase in abundance the farther away from the spring, with the exception of BBS22 CFIL.
7. *Quinquoculina seminulum* does not appear in ADGJ samples in either spring, and appears more frequently in BBS22 than in BBS21, with the exception of BBS22-M, where it is absent in 15-50% range, but present in the same range of BBS21-M.
8. *Elphidium discoidale* was present in the 15-50% range in few samples of each spring, but did not appear (in the 15-50% range) at all in the ADGJ samples of either spring.
9. For both springs, greater amounts of foraminifera in the 15-50% range are observed in both the ABC and JKL sample locations.
10. BBS21-M had four species in the 15-50% range, but all species in BBS22-M were less than 15% abundance.
11. More trends could be observed when looking at all the different abundance groupings (<15%, 15%-50%, and 50%-100%). The middle range was used to represent the fact that there are *some* trends present between both sediment locations, and springs.

Generally recognized paleoecological traits of some of more important benthic foraminifera that has assisted in the evaluations follow.

a. *A. beccarii*: Florida Bay studies show greater abundances closer to mainland, where there is freshwater runoff from land [1]. *A. beccarii* was also associated with estuarine assemblages in foraminiferal studies conducted along the coast of South Carolina [3]. From [3], this species did appear, however, in hypersaline, normal marine, and salt marsh environments as well. Studies from [3] also define *A. beccarii* as a pollutant indicator.
b. *A. beccarii v. parkinsoniana* was observed in the greatest quantities closest to the FL mainland in FL Bay studies [1].
c. *T. trigonula* is widespread in FL Bay studies, absent only from restricted areas of the Bay and deeper waters [1].
d. *T. oblonga* is present in lagoonal habitats world-wide [3].
e. *T. rotunda* is widespread and tolerant, and appears in FL Bay near fresh water regions [2].
f. *E. discoidale* is indicative of brackish water environments [1], [2], and [3].

IV. Conclusions

1. Artesian groundwater spring discharge is an extremely important source of leakage from the mainland in areas where fresh groundwater has significant head near the coast. Springs are especially important in the area from about two kilometers north to four kilometers south of the Deering Estate area of Cultler.
2. A number of springs discharge throughout the wet and dry season. These persistent springs have strong flow at low tide during the dry season and through the tidal cycle during the wet season.
3. Other smaller springs are ephemeral, flowing only during the wet season. When the adjacent freshwater groundwater table is high, there is a high density (one to several per square meter in areas) of these small springs extending from near shore off at least one kilometer.
4. In addition there is persistent artesian flow from the bottom and walls of dredged canals and boat basins and natural mangrove channels in the coastal wetland.
5. Most of this offshore fresh groundwater flow is through an open interconnected network or conduits in the limestone. Within ½ kilometer of cut channels springs tend not to occur on the natural bay-bottom surface. When flood channel gates are opened, even the most persistent springs drastically reduce flow.
6. One spring BBS21, also called the "Ricisak" spring was instrumented for multiple parameter measurements. This spring had dimension of 2 meters by 3 meters, approximately and was surrounded by plant growth. Within the spring multiple exit holes were observed in the bottom, so that the spring consists of, potentially, multiple-hole flows.
7. Spring flow during dry season (as inferred from salinity and temperature observations) was observed to be affected by the tides in Biscayne Bay. Flow was significantly reduced during the high tides and increased during the low tides. This suggests that the pressure head created by the tides is adequate to significantly reduce and possibly (almost) eliminate spring flow.

8. During periods of high tides, salinity values, e.g. 29 to 30 ppt, typical of Bay values were observed at the entrance of the BBS21 spring. During the periods of low tide, low salinity values, e.g. 9-10 ppt, were observed.
9. Lowest salinity values were observed approximately mid point between high and low tides (ebb) and low to high tides (flood).
10. Flow out of the springs was reasonably energetic as determined both by spring flow impact from the Bay water surface and “manual” judgments. A transverse Doppler inserted into a hole of spring BBS21 failed due to leakage. An unreliable estimate of flow of 6 cm/sec was retrieved from the instrument, possibly, prior to failure.
11. Chemical samples gathered at the three different springs (BBS21, BBS22, BBS26) yielded silica values ranging from 39.7 micromoles to 68.2 micromoles. The presence of silica supports the argument that the spring water samples are indeed groundwater.
12. Comparison of silica, ammonium and phosphate with other Biscayne Bay samples (see Table 3 on the Appendix) show that the values of these quantities at the groundwater spring are elevated when compared with the other Bay water samples from the Florida Bay Program. Silica values, roughly the same as groundwater spring values, were observed at Bay samples sites closest to canal discharges.
13. Through the dry and wet season observations the water discharge from the persistent springs was acidic (pH less than 7). This is verified by the predominance of quartz sand and the main loose sediment within the openings of the larger persistent springs (the carbonate having been dissolved).

VII. Recommendations

The large volume of water recognized as discharging through artesian spring conduits has very significant implications for the proposed re-establishment of freshwater sheet flow through the coastal wetlands of central and south Biscayne Bay. The groundwater spring conduits will an important part of how introduced water flows into Biscayne Bay under increased freshwater head.

We thus recommend a follow up effort to document the volumes of discharge through groundwater conduits under varying freshwater head conditions.

This exploratory study has encountered multiple difficulties in detecting and characterizing groundwater spring discharge in Biscayne Bay. Despite these difficulties, significant data has been obtained. To more fully characterize groundwater flows, both wet and dry season observations are required. The present exploratory study has obtained data primarily in the dry season. The analysis of sediment data by Dr. Hal Wanless will continue beyond the December 6, 2004 final report date at least to the end of their contract in January 2005.

A project of one year in duration is a very short time to locate, sample and instrument springs to obtain both wet season and dry season data. Now that the appropriate measurement sites have been determined, working sensors obtained and the logistical and personnel base established, it is recommended that the SFWMD make available additional funds for future sediment data analysis and spring measurements during varying levels of the adjacent fresh groundwater. It would be hoped that we could work out a schedule with the South Florida Water Management District management of the water control structures to create differing water levels for analysis.

VIII. REFERENCES

[1] Bock, W.D., Lynts, G.W., Smith, S., Wright, R., Hay, W.W., and Jones, J.I., 1963, A Recent Symposium Of Recent South Florida Foraminifera, Memoir 1: Miami Geological Society, 245 p.

[2] Rose, P.R., and Lidz, B., 1977, Diagnostic Foraminiferal Assemblages of Shallow-Water Modern Environments: South Florida and the Bahamas: Sedimenta VI, Miami, FL, University of Miami CSL, 55 p.

[3] Scott, D.B., Medioli, F.S., and Schafer, C.T., 2001, Monitoring in Coastal Environments Using Foraminifera and Thecamoebian Indicators: Cambridge, UK, Cambridge University Press, 177 p.